

RETRIEVING OPTICAL CONSTANTS AND GRAIN SIZE OF GLASSES BY HAPKE MODELING.

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Introduction: Visible and Near Infrared (VNIR, ~0.4-2.5 μm) spectroscopy is an important tool to explore the mineralogical surface composition of objects in our Solar System. To identify and quantify the mineral phases several techniques can be used, one of these is to apply a radiative transfer model, e.g. Hapke model [1,2]. Because the inner planets are characterized by extrusive volcanism and impact cratering processes, silicates glassy components can be abundant and thus significantly influence the spectral signatures and so the mineralogy we extrapolate.

Moreover the grain sizes of an individual component and its distribution is another important factor that influences the mineral and glass abundance determined from Hapke modeling. Here we report an initial effort of retrieving the optical constants of volcanic glasses formed in oxidizing terrestrial-like conditions, and a preliminary investigation on how those calculation are affected by the grain size distribution of a “regolith”.

Analytical approach:

Sample preparation and compositions. Four glasses were produced by melting different rocks type at 1500°C for one hour in terrestrial oxidizing conditions [see 3]. Different grain sizes (g.s.) were produced via grinding and sieving of the glasses to nine different sizes (20-50, 50-75, 75-100, 100-125, 125-150, 150-180, 180-200, 200-224, and 224-250 μm) all with ~25 μm dispersion within the sieve fraction. Additionally, g.s. mixtures were produced between 50 and 125 μm and between 125 and 250 μm , with variable weighed distribution of the three 25 μm subranges.

The reflectance spectra of all the g.s. and mixtures were measured in the VNIR (0.35-2.50 μm) with an incidence angle of 30°, and an emission angle of 0° with a ASD Fieldspec spectrophotometer at the IAPS, INAF, under standard laboratory conditions. The real part of the refractive index, at 0.59 μm , was measured calculating the Brewster angles and assuming that the imaginary index is ~ five order of magnitude smaller in the VNIR.

Additionally, original bulk rock and glass compositions were characterized with XRF of major elements, and Fe oxidation state was investigated with Mossbauer spectroscopy. These data will be used to relate mineralogical and chemical information with the spectral parameters.

Computational tools and assumptions. The basic approach to retrieving the optical constants was to use multiple g.s. of the same sample and assume all g.s. compositionally equivalent. As described above, n is

determined for the glasses and an initial assumption is that it is constant for all wavelengths.

The Hapke model [1,2] of the interaction of light with particulate surfaces was used to determine the imaginary index, k, at each wavelength by iteratively calculating the reflectance and comparing the result to the measured reflectance using a χ^2 -criterion. The interested reader is referred to [4] for more details regarding the exact equations. The median g.s. for each particle size separate was adopted for initially estimating k. Then, iterating the Hapke analysis results with a subtractive Kramers-Kronig analysis we were able to determine the wavelength dependence of n [5,6].

For each composition we used the k-values estimated for all the grain sizes to calculate a mean k-value representing that composition. These values were then used to fit the original spectra by only varying the g.s.. With the same approach the g.s. of the mixtures have been calculated considering a possible monodisperse distribution or a three subranges distribution.

Results and Discussion: The calculated effective k's (e.g. Fig. 1) are quite uniform, all lying within one sigma of the mean with the exception the smallest grain size (20-50 μm), see also [3]. In Fig. 1 we show how the average values, including (ave) and excluding (ave2) the 20-50 μm grain size, and their standard deviations, vary for the iron-poor and the iron-rich samples, in which cases k values show the highest variability.

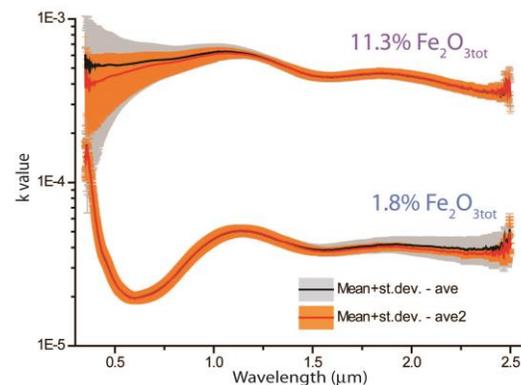


Figure 1 - Imaginary averaged indexes calculated from k of all the grain sizes (ave, black line) or without 20-50 μm (ave2, red line). The standard deviations are in grey and orange.

Because ave and ave2 are almost overlapping, at this preliminary stage we decided to consider ave as the most representative for each sample. Fig. 2 shows the four average k-values for the different glasses.

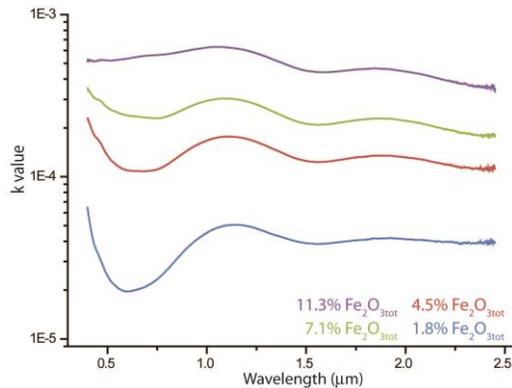


Figure 2 - Average k-values for all glass compositions (ave). All the grain sizes were used to calculate these mean values.

While the differences from ave and ave2 is very small, we used both, and the wavelength dependence n values, to calculate the best fit g.s. for each measured spectra of the four samples. Fig. 3 shows the fitted g.s. for the 1.8% $\text{Fe}_2\text{O}_{3\text{tot}}$ sample with both ave and ave2. In general, a similar trend is seen for all the samples with a fit grain size within the sieve limits.

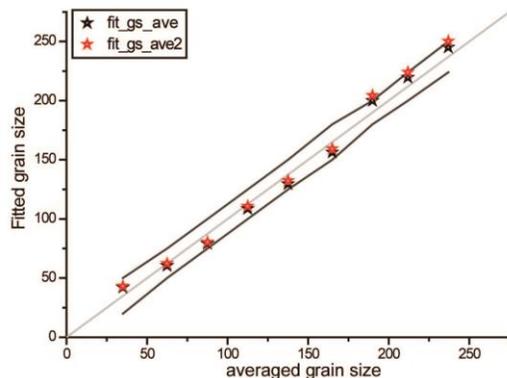


Figure 3 – Fitted grain sizes of sample A, using the two average k-values described in the text (description of fig.1) vs. the mean grain size value, based upon the sieve sizes. The black lines show the sieve size limits, and for comparison, the gray line illustrates a 1:1 correspondence.

In Fig.4 we show the measured spectra for the 50-125 μm g.s. mixtures of a composition of 4.5% $\text{Fe}_2\text{O}_{3\text{tot}}$. It is clear that for the same g.s. range, different distributions of the subranges affect the spectral signatures, in terms of reflectance and absorption intensity. For example, as the abundance of the subrange having the largest g.s. increases, the overall reflectance decreases, as previously reported for laboratory studies [7]. To understand the g.s. influences will strengthen our quantitative modeling.

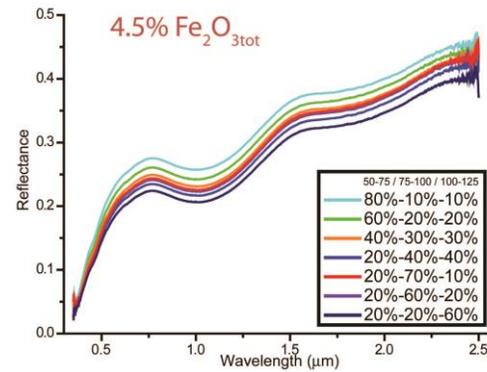


Figure 4 - Reflectance spectra for 50-125 g.s. range of 4.5% $\text{Fe}_2\text{O}_{3\text{tot}}$ composition for different distributions.

Preliminary conclusions and future work: With some further refinements the optical constants of these glasses will be available to model remote sensing observations of solar system surfaces.

We have evaluated how well the retrieved mean k-values can be used to estimate actual g.s. by fitting the measured spectra. We have found that the fitted grain sizes are always very close to the nominal mean g.s. values within the uncertainties of the sieving procedure. We have also considered mixtures of different g.s. within the same compositional domain to improve our capability in considering the impact on the retrieving of optical constants for wider grain size ranges. In the future we will consider transmittance measurements to compare retrieved k value from reflectance and transmission data with an approach similar to [6]. Additionally, we will investigate similar glass compositions that are formed in less oxidizing conditions that may be more relevant to atmosphereless surfaces of Solar System bodies.

References:

- [1] Hapke, B., 1981, *JGR*, 86, 3039-3054. [2] Hapke, B., 1993, Cambridge Univ. Press, New York, NY, 455pp. [3] Carli, C., et al. 2013, *44° LPSC*, #1918. [4] Roush, T., 1994, *Icarus*, 108, 243-254. [5] Roush, T., 2005, *Icarus*, 179, 259-264. [6] Roush, T., et al., 2007, *JGR-Planets*, 112, E10003, doi:10.1029/2007JE002920. [7] Adams, J. and A. Filice, 1967, *JGR*, 72, 5705-5715.

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